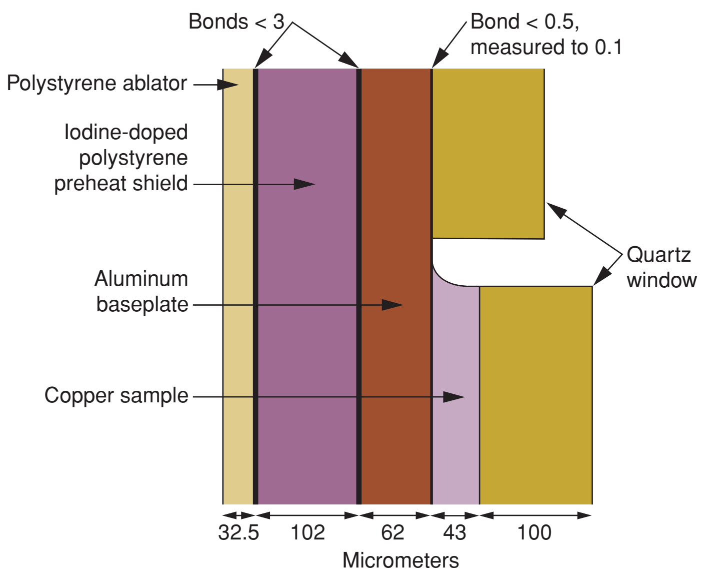
Zeroing In on New Targets

WHEN the National Ignition Facility (NIF) is completed and its 192 lasers are ready to fire, the force of the world's most powerful laser facility will likely be aiming at a very small and precisely fabricated target. Physicists preparing high-energy-density experiments intended for NIF are turning to Livermore engineers to help design, fabricate, and characterize super-tiny targets with minute tolerances.

NIF will be used to achieve ignition and to better understand physics at extremely high energy densities. The facility is critically important to ensuring the safety and reliability of the nation's nuclear weapons stockpile. Experiments on NIF will direct the force of a laser onto a target smaller than a poppy seed. Livermore's High Energy Density Physics (HEDP) Program, led by Charlie Verdon, has responsibility for an important series of experiments that will be conducted when NIF is completed. At present, experiments are being conducted on the OMEGA Laser at the University of Rochester's Laboratory for Laser Energetics. They include the measurement of key properties in materials such as equation of state (EOS), strength, opacity, and radiation transport.

Although precision and accuracy are always important in conducting scientific experiments, the specifications for the EOS targets are extremely precise and stringent. Because the results of the EOS laser experiments will be compared with computer simulations of expected material behavior, the exact size, shape, and orientation of each target must be known. Verdon says, "We are making significant advances in our target fabrication capabilities in order to achieve the desired physics understanding." A close collaboration between the physicists designing the experiments and the engineers fabricating the targets must occur to ensure the successful achievement of experimental goals.



Laser targets used to investigate the equations of state (EOS) of copper are composed of bonded layers of copper and aluminum foils and quartz windows (all units shown are in micrometers). The various layers of each EOS target must be fabricated to a uniform thickness for the experimental results to be accurate.

Putting Their Heads Together

Matthew Bono of the Engineering Directorate is involved in just such a collaboration. Bono and others from the target fabrication team are working with researchers from the Physics and Advanced Technologies Directorate to produce targets for experiments that will measure the EOS of copper.

Because of the accuracy desired in the experiments, the target specifications require a level of precision 10 times more stringent than that of most laser targets. Successfully designing the experiment and fabricating such precise targets requires a concerted effort by those involved. "As the designers of the experiments, we need to communicate with the target fabrication team to ensure the target can be realistically built while achieving the goals of the experiment," says physicist Peter Celliers.

Among the challenges in designing the targets is minimizing the variation in thickness of the materials that make up each target. The targets are composed of several layers of differing materials that are 4 millimeters in diameter and roughly the thickness of a piece of paper. These layers are stacked and bonded together to form the target.

According to Bono, one challenge is finding practical manufacturing solutions that will enable the team to deliver targets whose initial designs have proven difficult to build. When faced with challenges such as the EOS target, the engineers, machinists, materials scientists, and metrology experts on the team must often develop new capabilities that will lead to a successful manufacturing and metrology strategy. The result of the close collaboration between the target fabrication team and the physicists is a target design that satisfies all of the physics requirements and can be manufactured at an acceptable cost.

Shocking Copper

Livermore's expertise in target fabrication has proven critical for the upcoming EOS experiments on copper. In these experiments, the laser energy is directed onto the target's polystyrene ablator, which generates a shock wave that passes through an iodine-doped preheat shield. (See the figure on p. 18.) Part of the shock is transmitted through a layer of aluminum and then a quartz window, while the other part of the shock passes through the aluminum, then through the copper, and finally through another quartz window. To accurately measure the shock velocity, scientists must know precisely when the shock enters and exits both the aluminum and the copper as well as the thicknesses of the two metals.

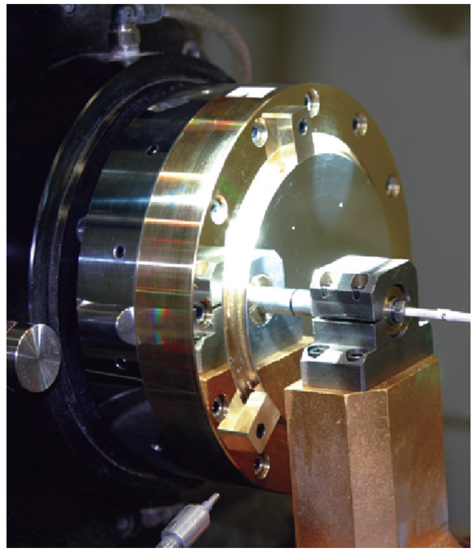
Because the shock must travel uniformly through the layers, the acceptable variation in the thickness of some layers is 0.1 micrometer. This thickness uniformity represents a tenfold increase in the level of precision of previously fabricated targets and was beyond the scope of standard target-fabrication practices at the onset of the effort.

Know How to Hold 'Em

Several fabrication methods were considered before selecting one that used a combination of diamond turning, deposition, and precision assembly. Because no practical methods currently exist to measure the targets adequately once they are built, the manufacturing process had to be designed to incorporate the required measurements of the components as they were fabricated and assembled.

Each target was built on a 100-millimeter-diameter aluminum disk that eventually became its paper-thin baseplate. To obtain components with uniform thickness, the team used a special vacuum chuck to hold the disk perfectly perpendicular to the machine tool. The vacuum chuck held the disk on a large number of very small concentric supports (only 50 micrometers wide), which were separated by much wider grooves. This small area of contact minimized the risk of dust or debris interfering between the baseplate and the chuck.

After diamond-turning both sides of the aluminum baseplate, a band of copper was deposited on the disk to form the copper sample of the target. The interface between the aluminum and the copper is crucial to the experiment. For the best possible interface, the copper was deposited directly on the aluminum using a combination of sputtering and electroplating. The sputter-seeded electroplating began with the removal of the oxide layer from the aluminum using an ion mill. Then a few micrometers of copper were sputtered onto the aluminum. Additional copper was electroplated onto the sputtered material, which was then diamond-turned to the correct thickness. All subsequent assembly operations and metrology were performed directly on the diamond-turning machine, which maintained the reference surfaces required to measure the thickness and uniformity of each layer of the target with the needed accuracy.



A special vacuum device holds the face of each disk perfectly perpendicular to the machine tool, which allows the components to be machined with uniform thickness.

After diamond-turning the aluminum disk to a paper-thin foil, several pads of iodine-doped polystyrene were bonded to it to form the preheat shields. The pads were epoxied in place using a special assembly fixture mounted directly on the machine tool. These pads were measured to determine the thickness of the adhesive layer and then machined to the required thickness. The process was repeated with polystyrene pads that formed the ablators. Because the workpiece remained on the vacuum chuck throughout this process, all surfaces were machined parallel to each other.

To create individual laser targets, the team cut 4-millimeter-diameter pieces of the bonded layers from the larger disk using an excimer laser. Quartz windows were then bonded onto the aluminum and the copper, and the target was bonded to a gold support ring, as shown in the figure on p. 20.

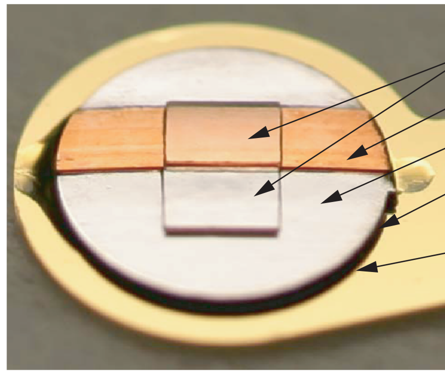
Measure by Measure

Because the amount of precision required to make and measure these targets is beyond those of industrial applications, some of the machines and tools to produce the targets must also be custom designed and fitted. “We often modify commercially available equipment to meet our requirements,” says Bono. “If we can’t buy a piece of equipment adequate for our needs, we make it ourselves.” Recent examples include a tool holder and an assembly station used to put together the tiny components.

Metrology tools used to precisely measure and characterize the final target may also need to be redesigned or retrofitted. “You can’t make what you can’t measure,” says Bono, echoing a maxim from the trade. “We have many capabilities for precision machining, but advanced capabilities for metrology are limited.” To meet the future needs of target production, the team is developing various metrology devices designed for targets at the mesoscale. Among these devices are an absolute thickness measuring machine and a four-axis coordinate measuring machine with submicrometer resolution. The team has also begun using a radiographic device with a millimeter-wide field of view that uses x rays to image an object with submicrometer resolution.

Looking to the Future

Targets for future experiments on NIF will become more complex with more demanding requirements. Close collaboration between physicists and engineers will be essential to designing targets that meet physics requirements and are manufacturable. Materials scientists will need to produce novel raw materials that allow physicists to study important issues. Engineers will need to develop new manufacturing processes that enable Livermore’s machinists to fabricate the targets. Metrologists and nondestructive evaluation experts will face one of the most important challenges as they develop and use advanced characterization methods to measure the completed targets. The requirements for measuring the targets are often just as challenging as manufacturing them.



A finished EOS target is bonded to a 5-millimeter gold support ring.

The successful delivery of the copper EOS targets has contributed to the feasibility and time and cost effectiveness of future experiments. “In addition,” says Bono, “as we develop new fabrication techniques, they become a part of our tool box. The work we did on this copper target has already enabled a significant cost savings for another project.”

That’s right on target.

—Maurina S. Sherman

Key Words: copper targets, equations of state (EOS), laser targets, machine tools, National Ignition Facility (NIF), precision machining, shock velocity, target fabrication.

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